Implementation of Mamdani Fuzzy Logic Controller for Shooting Planning of Wheeled Soccer Robot

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Abstract. The Indonesian Wheeled Football Robot Competition is a robot competition where each team must be able to play football independently. To be able to play independently, each robot must at least have artificial intelligence that can perform basic movements of playing football, one of which is kicking the ball. These abilities include being able to estimate the strength of the kick, so that other robots can receive the ball easily and kick the ball at an angle that is difficult for the opposing robot goalkeeper to anticipate. The method used in this research is to use the fuzzy logic control method, the test will be divided into two, namely testing the passing kick to a teammate robot and testing the kick towards the opponent's goal. Of the 10 times testing the passing kick to a robot friend, the robot managed to make a kick that could be received properly by the receiving robot, where the passing success was 90%. And from 10 times testing the kick towards the goal, the robot successfully kicked towards the goal which was difficult to anticipate by the enemy goalkeeper robot, where the success of the kick towards the goal was 80%.

Keywords: Wheeled Soccer Robot, Fuzzy Logic Control, Solenoid Kicker.

1 Introduction

The Indonesian Robot Competition is an annual design and engineering competition in the field of robotics organized by the Ministry of Higher Education of the Republic of Indonesia. In this competition there are 6 divisions. One of them is the Indonesian Wheeled Soccer Robot Competition. This division applies rules that apply Middle Size League (MSL) match rules which are one of the robots matches in the Robot Soccer World Cup (RoboCup). In the MSL match, there are two robot teams, each team consisting of 5 robots. Each team must be able to play soccer independently. Just like a real soccer match, the team that scores more goals is the winner. To be able to play independently[1] each robot must at least have basic soccer skills, one of which is kicking the ball. This ability includes the ability to estimate the force of the kick, so that other robots can receive the ball easily and kick the ball to an angle that is difficult for the opposing robot goalkeeper to anticipate.

The Indonesian Robot Competition (KRI) often has a kicking system that uses electromagnetics, where the disadvantages of using electromagnetics are hardware complexity and high supply voltage but has the advantage of being easy to control the strength of the kick[2]. However, the application of this kicking system must be combined with other systems on the robot, such as a terrain detection system on the robot. In the past, the method of controlling kicks using solenoids on the Barelang robot team still used static values. Where this results in a kick that is not flexible so that when passing there is often a miss due to a kick that is too strong or too slow so that the ball is very easily captured by the enemy. For this reason, a way is needed to overcome these problems. Fuzzy logic is considered capable of mapping the input space to the output space. Fuzzy logic is considered very flexible and has a tolerance value for the data it has[3].

Research related to fuzzy logic control as a kick control on wheeled soccer robots has previously been carried out by Kurniawan Cahyono et al in 2020 with the title A New Kicker System of Wheeled Soccer Robot ERSOW Using Fuzzy Logic Method[4]. The journal discusses the decision-making system based on the distance and height input variables of the ball which are used to determine the motor speed and kick angle, resulting in the desired distance and height of the kick. The fuzzy logic control output in this study is in the form of an RPM value which is used to adjust the motor speed using PID control. So, it must calibrate the right PID value so that the motor speed used to kick is as desired. Based on this, this research is focused on making it easier to adjust the kicking force on the soccer robot kicker system using a solenoid that only gives the PWM value to the solenoid driver without doing other calculations.

The decision-making process when the robot kicks with fuzzy logic will be divided into two. First, regulating the strength of the kick during passing which will use two inputs, namely the distance of the receiving robot and the distance of the opposing robot. Second, decision making when the robot kicks towards the goal will use two inputs, namely the distance of the opponent's goal and the distance of the opponent's robot. From the two applications of the fuzzy method, a PWM value will be obtained which will regulate the power of the kick on the robot. The purpose of this research is to adjust the kicking force on a wheeled soccer robot using fuzzy logic control and analyze the performance of a wheeled soccer robot when passing and kicking towards the opponent's goal. The results of this study are expected to provide benefits to reduce the occurrence of missed passes due to kick strength that is too strong or slow so that the receiving robot can catch the ball properly.

2 Method

The design of the kick planning control system for soccer robots is designed by processing data from object detection which will be used as input for fuzzy logic control, Fig. 1 shows the design system used in this research. There are several parameters needed, namely the distance of the opponent's robot, the distance of the receiving robot, and the distance of the opponent's goal. The distance data of the opponent robot is obtained through omnidirectional camera detection using the color segmentation method, the distance of the receiving robot is obtained from communication between robots whose data is stored in the robot strategy and the distance of the opponent's goal is obtained from the opponent's goal coordinate data that has been determined in the robot strategy. The coordinates of the kicking robot are obtained from the reading of the rotary encoder by the STM32F407, the coordinate data of the kicking robot will be calculated with the distance of the kick goal, where the kick goal will be selected based on the kick scheme. In the design of passing kicks and kicks towards the goal on this soccer striker robot consists of several schemes, namely first, the scheme for passing where the robot will get the parameter value of the object that has been detected in the form of the parameter value of the distance data of the opponent robot and the distance of the recipient robot. Second, take a kick towards the goal by getting the coordinates of the goal and the distance of the opponent robot. Furthermore, the value of the two parameters in each kick scheme will be calculated using fuzzy logic control which will produce an output in the form of PWM to regulate the strength of the kick.

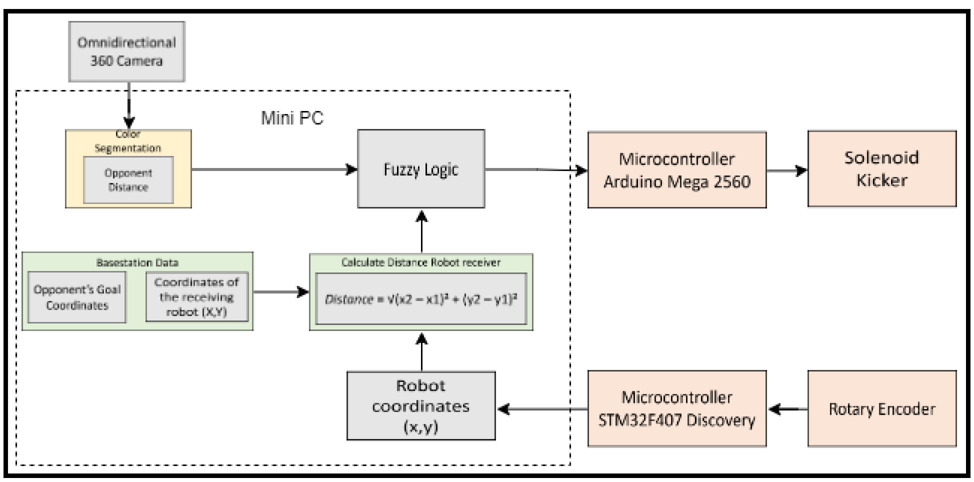


Fig. 1 Control System Diagram

2.1 Object Detection

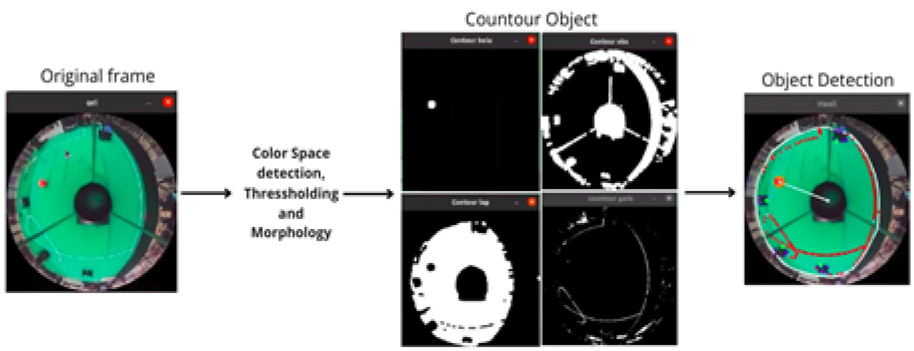
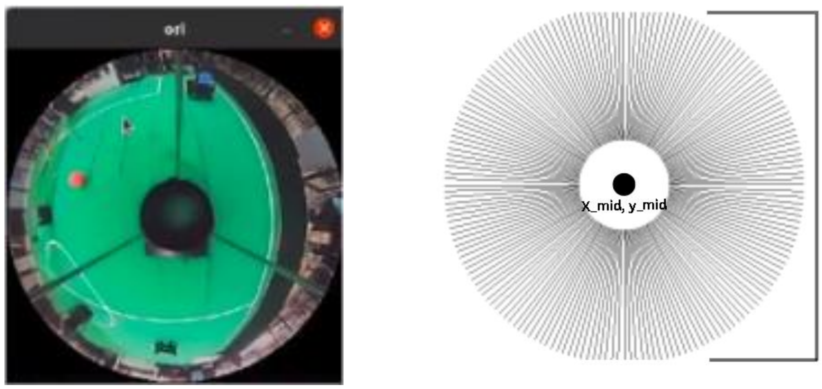


Fig. 2 Object Detection

Determining detected objects involves using color space as a tool for color selection, which aims to identify, create, and visualize individual colors. Due to the subjective nature and variations in the color space process, the main purpose of using color space is to describe the color differences between objects and to standardize the approach. In addition, thresholding techniques are also used to increase the sensitivity of color space results by setting threshold values that are used to identify objects based on differences in brightness or darkness in the image. There are also morphological transformation techniques that help in the identification of target regions. Morphological transformation is a process that involves manipulating a binary image by changing pixel values, comparing pixel values, and changing the structure of the original values in the image frame. Morphological transformation consists of two main components, namely erosion which is used to remove the boundaries of the object and merge it with the background based on the texture elements used, and dilation which is used to merge the background points into the object considering the texture elements, thus increasing the size of the object by adding binary values as seen in Fig. 2.



(a) (b)

Fig. 3 (a) Input frame (b) Radial scanline

After receiving color information and undergoing a morphological transformation process with some filtering to get good color and contour image results on the input frame, the next stage is to use the scanline method to extract the white lines in the field. There are several types of scanline detection: radial, vertical or horizontal and circular scanline. The method applied to this detection is the radial scanline which is shown in Fig. 3. The image extraction process with this scanline method is broken down into rows of pixels sequentially and processing starts from the first row to the last row. Each row or pixel is analyzed or processed separately, and the detected points have different angular values and distances from the center position of the frame on the robot.

2.2 Fuzzy Logic Control Input Parameters

In this subsection, we will discuss the parameters that will be used as input from fuzzy logic, where the value of these parameters will produce an output in the form of PWM which is used to control the kicking power of the robot. The following are the parameters used as fuzzy logic input to control the kicking power of the soccer robot:

Distance of Robot Opponent

The distance of the opponent robot can be known through the points marked on the object detection system by using the color segmentation method and calculating the distance of the green dot in Fig. 4, with the robot then selecting the closest point as the distance data of the opponent robot.

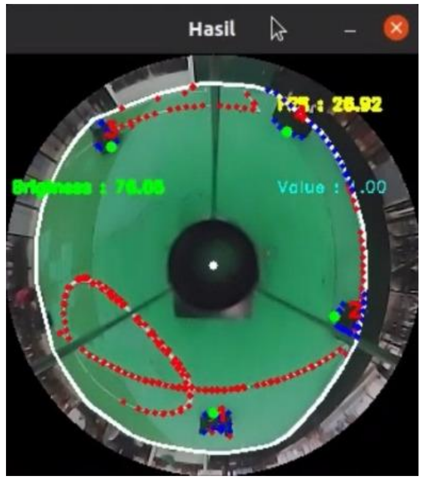


Fig. 4 field area detection results using an omnidirectional camera

Kick Goal Distance

The distance of the kick goal is obtained from reading the position of the robot using a rotary encoder with the Odometry method[5], and the goal coordinates that have been known by the robot through strategy, then the two goal distances will be calculated with the position of the robot that will kick the ball using the Euclidean Distance Method. The Euclidean distance method is the distance between two points in Euclidean space defined as the length of a line segment between two points. The Euclidean distance formula used is found in Equation 1:

$$Euclidean\ Distance = \sqrt{[(x_2 - x_1)^2 + (y_2 - y_1)^2]} \quad (1)$$

X_1, Y_1 = *Coordinates of the ball-kicking robot*
X_2, Y_2 = *Kick destination coordinates*

2.3 Mechanics Design

The mechanical materials used to make robots are aluminum and iron. Aluminum material is used to make parts that are on the robot, while iron is used to make a solenoid shield to reduce electromagnetic waves generated when the solenoid works.

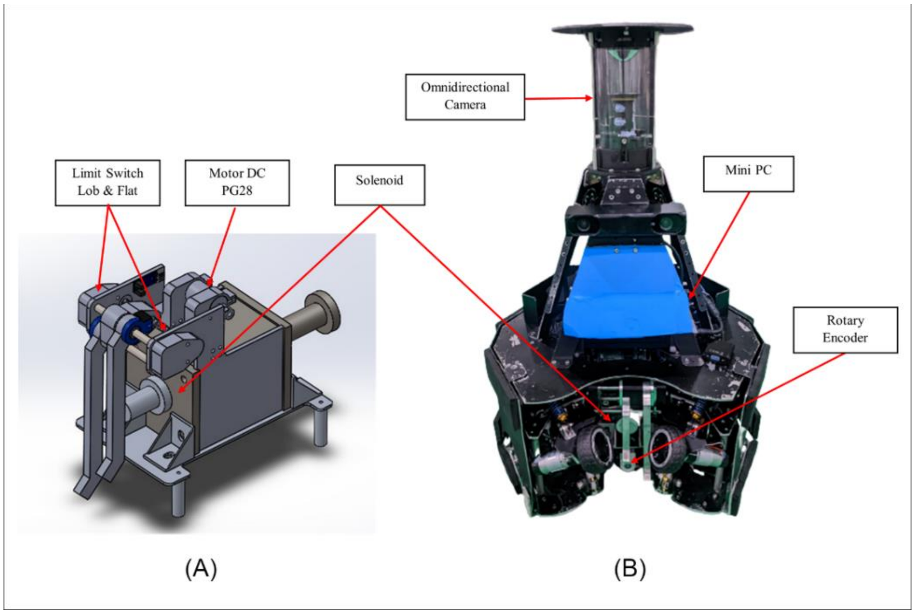


Fig. 5 Mechanical design of the Barelang 63 robot kicker system (A) and Barelang 63 Soccer Robot Mechanics (B)

Fig. 5 (a) is the design of the robot kicking system, there are two legs or limbs kicking the ball where the short leg is used to feed towards the receiving robot and the long leg is used to kick towards the opponent's goal so that the enemy robot is difficult to anticipate the lob ball[6]. In Fig. 6 (b) is the overall shape of the robot made of aluminum plate to be strong against the impact that occurs during the match.

2.4 Hardware Design

The hardware design is focused on the robot kicking system using solenoids which consists of several components used in the robot. Fig. 6 is the hardware design of the kick power planning on this soccer robot using two different batteries, namely 3 cell and 6 cell lipo batteries. The 3 cell lipo battery is used as an input voltage supply to the ZVS Boost Converter[7] which will be used to charge the electric charge into the capacitor bank (4700 uF 450 v) and also as a gate trigger voltage on the IGBT contained in the solenoid driver[8] which is regulated by the TLP250 gate driver. The 6 cell battery is used as a mini PC input voltage supply and microcontroller which is used to regulate actuators and read sensor data contained in the robot. In this hardware design there are several sensors used, among others: Omnidirectional camera connected to a mini PC using USB which functions as an object detector around the robot[9]. Rotary encoder is used to determine the position of the robot in the field using the odometry method[10]. Limit switch is used to confirm the position of the kicker's foot in the lob kick or flat kick position, and the Proximity sensor is used to validate the ball is already in the dribbling system and ready to be kicked if the proximity data and limit switch are not read, the robot will not be able to kick.

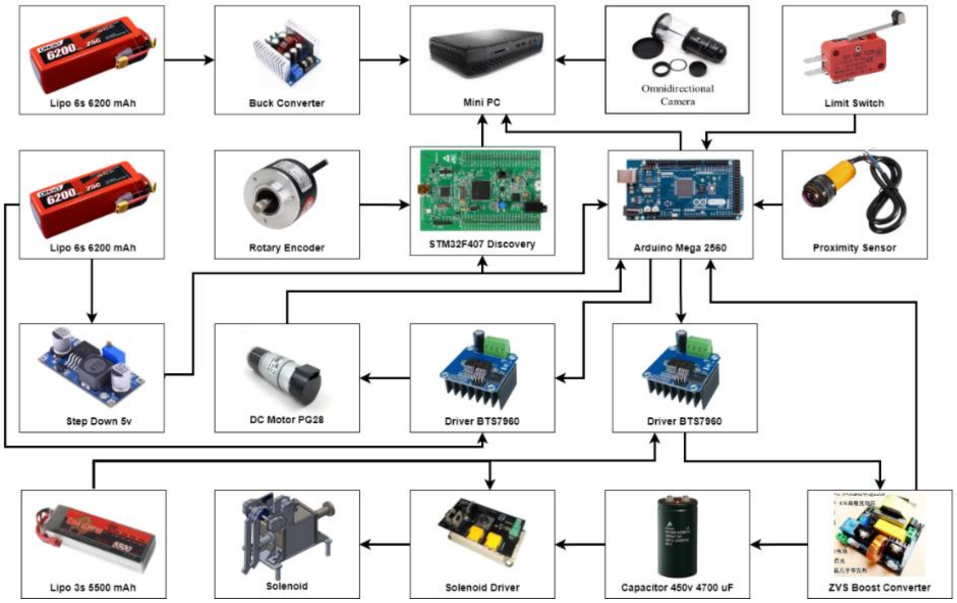


Fig. 6 Hardware design diagram

2.5 Fuzzy Logic Control Design

Fuzzy logic control is a control system that utilizes logic where to determine the output must design inputs in the form of uncertain data and will be operated into crips values[11]. Fuzzy logic control has three main functions as follows:

Fuzzification

Fuzzification is the process of converting crips input values into fuzzy sets. The membership formation in this study uses two membership functions, namely triangle and trapezoid[12], where the membership formation used is in Fig. 7 and Fig. 8.

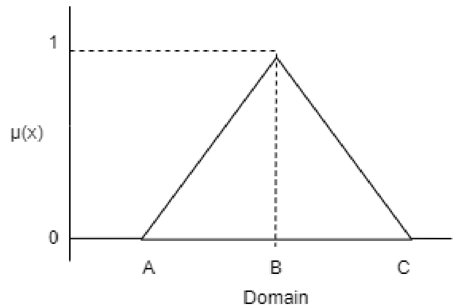


Fig. 7 Triangular membership function

The membership function of the triangular curve representation can be seen in Equation 2:

$$\mu(x) = \begin{cases} 0; \; x \le A \text{ or } x \ge C \\ \frac{x-A}{B-A}; \; A \le x \le B \\ \frac{C-x}{C-B}; \; B \le x \le C \end{cases} \quad (2)$$

μ(x) = Degree of membership.
A = the smallest domain value when the membership degree is small.
B = the membership degree that has the largest value in the domain.
C = the domain value when the membership degree is smallest

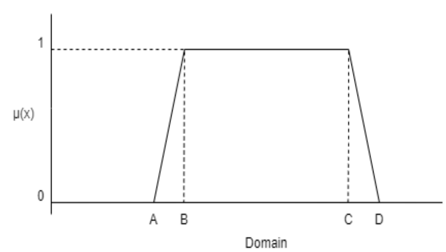


Fig. 8 Trapezoidal membership function

The membership function of the trapezoidal curve representation can be seen in Equation 3:

$$\mu(x) = \begin{cases} 0 \; ; \; x \le A \text{ or } x \ge C \\ \frac{x-A}{B-A}; \; A \le x \le B \\ 1 \; ; \; B \le x \le C \\ \frac{D-x}{D-C} \; ; \; C \le x \le D \end{cases} \quad (3)$$

μ(x) = Degree of membership.

A = the smallest domain value when the membership degree is small.
B = the membership degree that has the largest value in the domain.
C = the membership degree that has the largest value in the domain.
D = domain value when the membership degree is smallest.

The input of this fuzzy logic control will use data on the distance of the opposing robot, the distance of the receiving robot, and the distance of the opponent's goal which will produce output in the form of kick strength data for passing and shooting.

Distance of opponent robot

The distance of the opponent robot is one of the inputs used in making the Fuzzy Logic Controller method in this project. The input of the distance of the opponent robot is to determine the distance of the opponent robot according to the situation in the field. The following are the variables of the ball drop distance membership function:

- Danger
- Bit Danger
- Safe

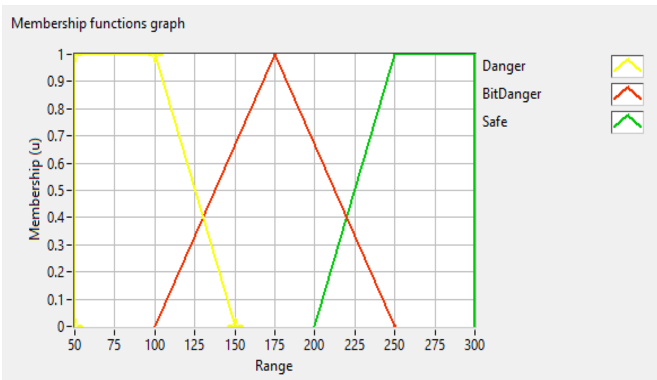


Fig. 9 Distance membership of opponent robot

Note* The numbers on the y-axis ranging from 0 to 1 are the membership degree values and the numbers on the x-axis ranging from 50 to 300 are the distance values of the opponent robot.

Distance Robot receiver passing

The distance of the receiving robot is the second input used in the fuzzy logic control method in this project. The receiver robot distance membership variable is set from 50 cm to 800 cm.

- Near
- Bit Near
- Medium
- Bit Long
- Long

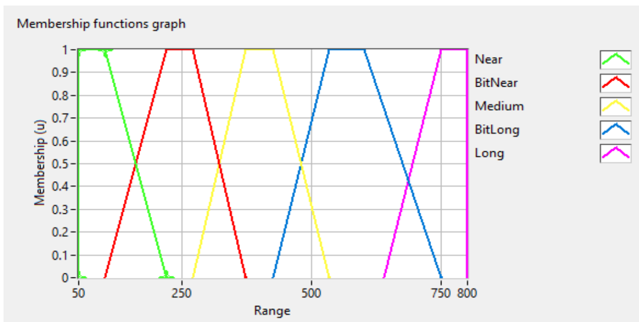


Fig. 10 Membership Distance Robot receiving the ball when passing

Note* the number on the y-axis is the membership degree value and the number on the x-axis is the value of the distance of the opponent.

Opponent's Goal Distance.

The destination distance is the third input used in the fuzzy logic control method in this project. The destination distance membership variable is set from 100 cm to 500 cm.

- Close
- Bit Close
- Moderate
- Bit Far
- Far

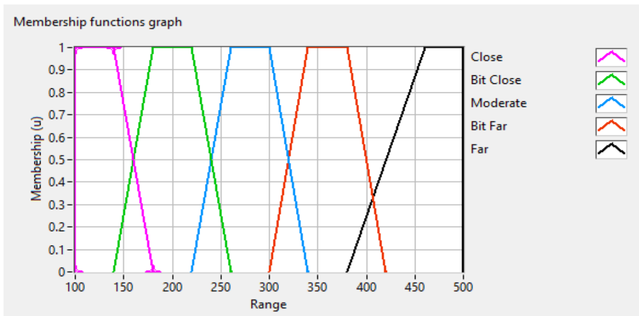


Fig. 11 Membership distance of opponent's goal

Passing kick strength

The first fuzzy method output is the value of the robot's kicking force at the time of passing. The membership variable of the passing force to the receiving robot is set from PWM 5 to 50.

- Slow
- Middle
- Fast
- Very Fast
- Very Slow

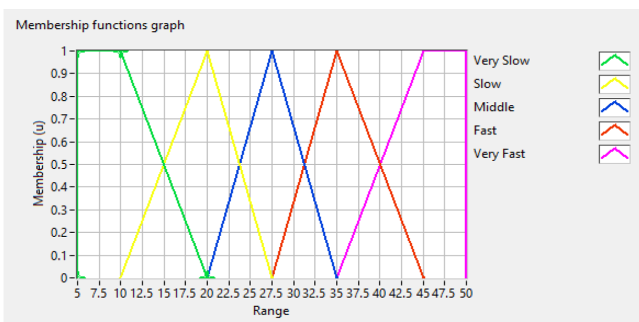


Fig. 12 Passing kick strength membership

Kick strength to goal.

The output of the second fuzzy method is the value of the power of the kick towards the goal which is used to regulate the power of the ball kick towards the goal. The membership variable of the kick strength towards the goal is set from PWM 45 to 85.

- Very Weak
- Weak
- Medium
- Strong
- Very Strong

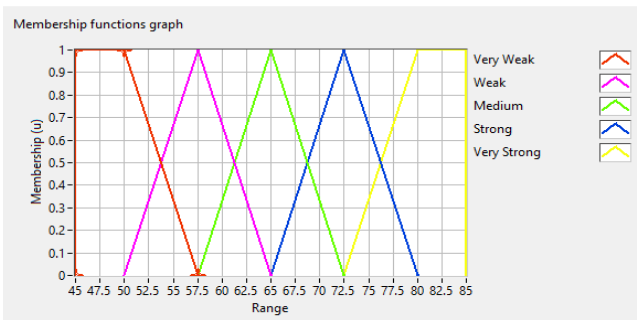


Fig. 13 Membership of kick strength to goal

Inference

Inference is the process of forming a Rule that describes how the system should react to inputs. All membership variable functions formed from input to output are filled in according to the previously created rule table, so that the membership variable can be used in the next process. In Table 1, blocked in light blue is the Rule used for passing kicks to the receiving robot. This rule allows the kicking robot to pass to a teammate with input parameters in the form of the distance of the opposing robot and the distance of the receiving robot.

Table 1 Rule Base for passing kicks and kicks towards the opponent's goal

Kick Mode		Opponent Robot		
Passing		Danger	Bit Danger	Safe
Receiving Robot Distance	Near	Very Slow	Very Slow	Very Slow
	BitNear	Slow	Slow	Slow
	Medium	Middle	Middle	Middle
	BitLong	Bit Far	Bit Far	Bit Far
	Long	Far	Far	Far
Kick to the opponent Goal		Danger	Bit Danger	Safe

Goal Distance	Close	Very Weak	Very Weak	Very Weak
	Bit Close	Weak	Weak	Weak
	Moderate	Medium	Medium	Medium
	Bit Far	Strong	Strong	Strong
	Far	Very Strong	Very Strong	Very Strong

The power rule for kicks towards the opponent's goal is in Table 1 which is blocked in light orange. This rule allows the robot to kick towards the goal with input parameters in the form of the distance of the opponent's robot and the distance of the intended opponent's goal. In this design, rule evaluation uses the Mamdani method (max of min implication method) as shown in Equation 4.

$$\mu C(z) = min[\mu A(x), \mu B(y)] \tag{4}$$

$\mu_A(x)$ = Membership degree of the distance of the opponent robot.
$\mu_B(y)$ = Membership degree of kick destination distance.
$\mu_C(z)$ = Output membership degree.

Defuzzification

The result of the defuzzification process is a set of fuzzy values obtained by combining fuzzy rules. The result obtained is a number that is within the range of the fuzzy set. In other words, if there is a fuzzy set within a certain range then certain specific values can be taken as output[13]. The Center of Area defuzzification method is obtained by taking the center point of the fuzzy area. In general, the Center of Area calculation is detailed in Equation 5.

$$Z = \frac{\int \mu(z) z \, dz}{\int \mu(z) \, dz} \tag{5}$$

μ(z) = degree of membership of the output membership of fuzzy logic control.
Z = Output result of fuzzy logic control

3 Results

System testing is carried out to determine the success of the system made in this project. If the system is not as expected, it can be known the factors that cause the system not to be as desired. For system testing there are several parts including kick performance when passing and kick performance when kicking into the opponent's goal.

3.1 Distance of Robot Opponent

The distance of the opponent robot that will be used as input for fuzzy logic control is obtained from the detection results of the omnidirectional camera using the color segmentation method which can be seen in Fig. 14. Where there is a green dot that indicates an obstacle or an opposing robot.

Fig. 14 Detection results using an omnidirectional camera

Fig. 15 is the distance comparison data between the kicking robot and the opponent robot using the measuring instrument. In the distance data obtained from detection using an omnidirectional camera, the closest distance between the kicking robot and the opponent robot will be taken.

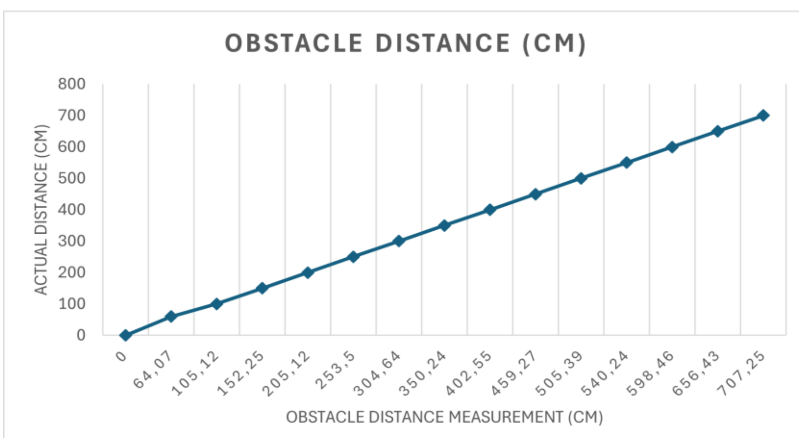


Fig. 15 Obstacle Distance data

3.2 Kick Goal Distance

The kick distance to the target will be divided into two different targets, namely when kicking towards the opponent's goal will use the opponent's goal coordinate data and when passing will use the coordinate data of the receiving robot. From the goal coordinate data, it will be calculated using the Euclidean Distance method with the coordinates of the ball kicking robot and the results will be used as input for the goal distance in fuzzy logic control. Comparison data of Euclidean Distance results with measuring instruments is presented in Fig. 16.

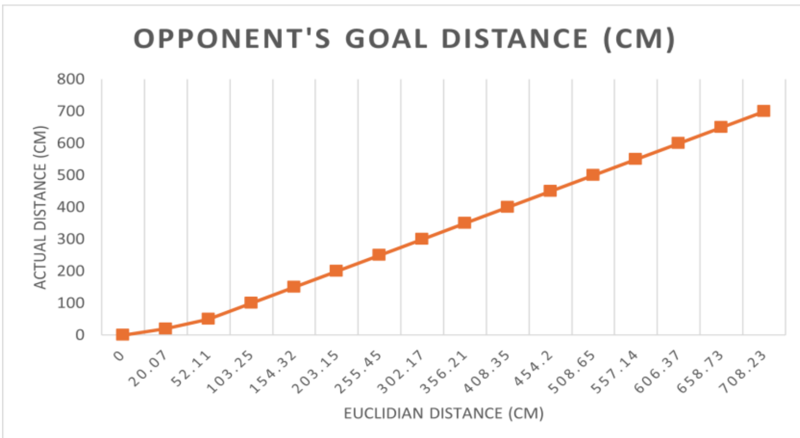


Fig. 16 Opponent's goal distance data

3.3 Fuzzy Logic Control Output

The input data in this experiment is in the form of distance data of the opposing robot, the distance of the receiving robot, and the distance of the goal. Furthermore, it will produce a Pulse Wide Modulation (PWM) value which will be used to set the gate leg on the IGBT contained in the Solenoid driver. Kick testing will be divided into two, namely testing a passing kick to a friend's robot and testing a kick towards the opponent's goal. Fig. 17 (a) shows the place used for kick testing, next is to try a passing kick using a futsal ball. To carry out this experiment, some supporting equipment is needed to facilitate measurement, namely using a meter used to measure the distance of the opposing robot and the distance of the receiving robot.

(a) (b)

Fig. 17 (a) Attempted passing kick (b) Attempted kick towards the opponent's goal

From 10 times testing the passing kick to a friend's robot, the robot successfully kicked a kick that could be received properly by the receiving robot, where the passing success was 90%, with 1 failure, that exists in the 5th test data, this failure was caused by the ball being kicked not exactly aiming at the position of the receiving robot so that the receiving robot was unable to catch the kicked ball.

Table 2 Performance results of passing kick using fuzzy logic control on Barelang 63 robot

Opponent Robot (cm)	Goal Distance (cm)	Status
100	200	Success
136	250	Success
157	270	Success
50	400	Success
80	450	Fail
285	300	Success
150	220	Success
100	135	Success
170	264	Success
170	392	Success

Fig. 17 (b) shows how to attempt a kick towards goal in the same way as attempting a kick during passing. Data on the success of kicks towards the goal can be seen in Table 3. Of the 10 tests, the robot successfully kicked towards the goal which was difficult to anticipate by the enemy goalkeeper robot, where the success of the kick towards the goal was 80%, with 2 failures, namely in the 4th and 6th test data, the failure in the 4th test was caused by a kick that was too wide so that the ball hit the goal post and the failure of the 6th trial was caused by the robot kicking towards the goalkeeper robot so that the ball hit the goalkeeper robot.

Table 3 Goal kick performance results using fuzzy logic control on Barelang 63 robot

Opponent Robot (cm)	Goal Distance (cm)	Status
180	438	Success
200	355	Success
300	270	Success
430	384	Fail
230	431	Success
280	475	Fail
400	424	Success
200	352	Success
200	423	Success
300	298	Success

4 Conclusion

Based on the results of research on the implementation of fuzzy logic control as a method used to regulate the power of kicks on the Barelang mobile robot soccer team, to perform passing and shooting towards the opponent's goal, it can be concluded that Fuzzy Logic Control with input from the distance of the opponent's robot, the distance of the receiving robot, and the distance of the opponent's goal can provide good performance in passing to teammates and kicking towards the opponent's goal based on parameters found in the field. There are failures in performing passing kicks and kicks to the opponent's goal due to the inappropriate angle of the robot's face so that the ball fails to lead right to the kick destination resulting in the ball not being received by a teammate robot and the ball does not enter the opposing team's goal. Using the fuzzy logic control method can improve teamwork and the success of the soccer robot game in winning the match.

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